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N. K. Fageria[a]; V. C. Baligar[b]
[a] National Rice and Bean Research Center of EMBRAPA, Goiania-Goias, Brazil [b] USDA-ARS, Appalachian Soil and Water Conservation Research Laboratory, Beaver, WV

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Yield and Yield Components of Lowland Rice as Influenced by Timing of Nitrogen Fertilization

N. K. Fageria[a] and V. C. Baligar[b]

[a]*National Rice and Bean Research Center of EMBRAPA, Caixa Postal 179, Goiania-Goias, CEP 74001-970, Brazil*
[b]*USDA-ARS, Appalachian Soil and Water Conservation Research Laboratory, P.O. Box 400, Beaver, WV 25813-0400*

ABSTRACT

Insufficient nitrogen (N) supply is an important constraint to productivity of lowland rice *(Oryza sativa* L.), and there is limited information available on optimum timing of N application for lowland rice. To determine the effects of timing of ammonium sulphate application on yield, yield components, and N-use efficiency of lowland rice, a greenhouse experiment was conducted on an Inceptisol (Typic Haplaquepts). The 1,200 mg N application timing was: i) total at sowing (T_1); ii) one-third at sowing + one-third at active tillering + one-third at panicle initiation (T_2); iii) one-third at sowing + one-third at panicle initiation + one third at booting (T_3); iv) one-third at planting + one-third at panicle initiation + one-third at flowering (T_4); v) zero at sowing + one-half at the initiation of tillering + one-half at panicle initiation (T_5); and vi) zero at sowing + one-third at the initiation of tillering + one-third at booting + one-third at flowering (T_6). Dry matter, grain yield, N uptake, and N-use efficiency were significantly affected with timing of N application treatments. Maximum grain yield was obtained with the T_1 treatment, followed by the T_2 and T_5 treatments. Treatments T_4 and T_6 produced minimum grain yields. Nitrogen treatments had highly significant ($P<0.001$) effects on the number of panicles, followed by filled ($P<0.01$) and unfilled ($P<0.05$) spikelets. The number of panicles was the most important component of yield, accounting for about 87% of the variation in yield.

INTRODUCTION

Rice is one of the oldest cultivated crops on the earth. It is a staple food of more than 50% of the world population, including peoples of Asia, Africa, and South America. The world population of about 5.5 billion today is likely to reach about 6.2 billion in the year 2000 and about 8.3 billion in 2025. Total demand for rice will probably increase 70% during the next 30 years, thus 350 million more tons of rice will have to be produced by 2025 (IRRI, 1994).

The judicious use of available technologies and the development of new technologies are fundamental for achieving desired yield potentials. Nitrogen is the single most important production input, and it is the most limiting nutrient for flooded or lowland rice production worldwide (Becker et al., 1994; Baligar and Fageria, 1997). Making accurate N fertilizer recommendations for higher N-demanding crops like lowland rice is becoming more important as concern grows about the high cost of this input and nitrate pollution of surface and ground waters in agricultural areas. Fageria and Baligar (1996) have reported that lowland rice yields in central Brazil on Varzea soil were significantly higher at 200 kg N ha^{-1} than at 100 kg N ha^{-1}. Timely and split application of N may improve a crop's response to N, especially at high rates. Split application of N also allows for more efficient use of N throughout the growing season as it provides specific amounts of nutrients to the crop during peak periods of growth and may reduce leaching of nitrate-N in the soil. Most of the studies (Castillo et al., 1992; Guindo et al., 1994) on N fertilizer management for lowland rice as affected by timing of application have examined the effect of only one or two split applications in the early stage of crop growth. Few studies (Wilson et al., 1989) have examined the several timings of N application covering vegetative and reproductive growth stages. Establishing the best timing of N for lowland rice is essential for improving N-use efficiency. This study was to determine appropriate timing of split application of nitrogen on lowland rice.

MATERIALS AND METHODS

A greenhouse experiment was conducted at the National Rice and Bean Research Center of EMBRAPA, Goiania-Goias, Brazil, to evaluate the timing of N application on lowland rice. The soil used was an Inceptisol. It was collected (0-20 cm) from the National Rice and Bean Research Center's irrigated rice experimental station, Palmital, which is located about 20 km from the Center's headquarters. The soil analysis before the application of the N treatments had the following chemical properties: pH 5.4 (1:2.5 soil/water ratio), extractable P 12.5 mg kg^{-1}, extractable K 66.9 mg kg^{-1}, extractable Ca 5 $cmol_c$ kg^{-1}, extractable Mg 3.6 $cmol_c$ kg^{-1}, extractable Al 0.1 $cmol_c$ kg^{-1}, extractable Cu 3.8 mg kg^{-1}, extractable Zn 3.8 mg kg^{-1}, extractable Fe 143 mg kg^{-1}, extractable Mn 88 mg kg^{-1}, and organic matter content 20 g kg^{-1}. Phosphorus (P), potassium (K), zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn) were extracted by the Mehlich 1 extracting solution (0.05M HCI + 0.0125M H_2SO_4). Phosphorus was determined colorimetrically, K by flame photometry, and all the micronutrients by atomic absorption spectrophotometry. Aluminum (Al), calcium (Ca), and magnesium (Mg) were extracted with 1M KC1. Aluminum was determined by titration with NaOH, and Ca and Mg by titration with EDTA. Organic matter content was determined by the Walkley and Black method. All the soil analysis methods used in this study are described in the manual of soil analysis of Embrapa (1979).

The treatments were: i) all the N applied at the time of sowing (T_1); ii) one-third of N was applied at sowing + one-third applied at active tillering (43 days after sowing) + one-third applied at pinacle initiation (T_2); iii) one-third at sowing + one-third at panicle initiation + one-third at booting (T_3); iv) one-third at planting + one-third at panicle initiation + one-third at flowering (T_4); v) zero N at sowing + one-half at the initiation of tillering + one-half at panicle initiation (T_5); and vi) zero N at sowing + one-third at the initiation of tillering + one-third at booting + one-third at flowering (T_6). Each treatment received 1200 mg N as ammonium sulphate. The experiment was conducted in plastic pots with 5 kg of air dry soil in each pot. At the time of sowing, each pot received 996 mg K as potassium chloride and 983 mg P as triple superphosphate. The cultivar used in the experiment was Javae, which was recently released by Embrapa and is recommended for the central part of Brazil for lowland rice. The pots were arranged in a completely randomized block design with three replications with three plants per pot. Before flooding, pots were maintained at about field capacity. Pots were flooded with water 13 days after sowing with a water depth of about 2 cm. This depth of water was maintained until about one week before harvesting, at which time the water was drained. Plant height, number of panicles per pot, dry matter per pot, grain yield per pot, filled and unfilled grains per pot, and 1,000-grain weight were determined. The plant material and grain were ground and digested with sulfuric acid for N determination. Nitrogen in the tops and grain was analyzed by a semimicro-Kjeldahl method (Bremner and Mulvaney, 1982) using a Kjeltec Systems Tecator 1016 digesting and 1004 distilling unit. On all data, analysis of variance was used, and means were tested by Tukey's test.

RESULTS AND DISCUSSION

Dry matter and grain yield of lowland rice were significantly affected by N application timing (Figure 1). Significantly ($P<0.05$) higher dry matter yield was

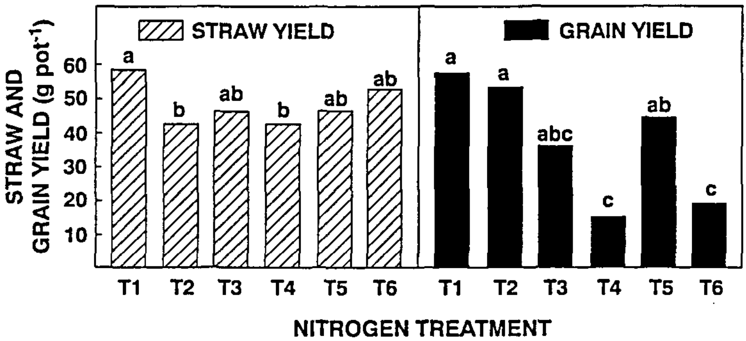

FIGURE 1. Straw and grain yield as affected by nitrogen timing treatments. T_1= all the N applied at the time of sowing; T_2 = one-third of N applied at sowing + one-third applied at active tillering (43 days after sowing) + one-third applied at panicle initiation; T_3 = one-third at sowing + one-third a panicle initiation + one third at booting; T_4 = one-third at planting + one-third at panicle initiation + one-third at flowering; T_5 = zero N at sowing + one-half at initiation of tillering + one-half at panicle initiation; and T_6 = zero N at sowing + *one-third at initiation of tillering + one-third at booting + one-third at flowering.*

produced under the T_1, T_3, T_5, and T_6 treatments as compared to the T_2 and T_4 treatments. Dry matter yield decrease under the T_2 and T_4 treatments was 27 and 28%, respectively, as compared to the highest-yielding T_1 treatment. Dry matter yield under the N treatments was in the order of T_1>T_6>T_5>T_3>T_2≥T_4. Highest grain yield was obtained with the T_1 treatment, followed by the T_2 and T_5 treatments, and minimum under the T_4 and T_6 treatments. The grain yield reduction under the T_4 and T_6 treatments was 74 and 69%, respectively, as compared to the T_1 treatment. The grain yield-producing order under different treatments was T_1>T_2>T_5> T_3>T_6>T_4. Dry matter and grain yield did not follow the same order under different N treatments, and grain yield was more influenced by N timing as compared to dry matter production. Plant height, 1,000-grain weight, and harvest index were not affected significantly by the N treatments. However, the number of panicles and number of filled and unfilled spikelets were significantly affected with N treatments (Table 1). The number of panicles produced was highest under the T_1, followed by T_2 and T_5, respectively. The decrease in the number of panicles under T_4, T_6, and T_3 treatments were 71, 58, and 49%, respectively, as compared to T_1 treatment. Higher grain yield under T_1, T_2, and T_5 in this study was due to more number of panicles and filled grain. Gravois and Helms (1992) reported that, among different yield components of rice, panicle density had the largest positive direct effect on rice yield. They also reported that path-coefficient analysis revealed that effects

TABLE 1. Plant height and yield components under different N treatments.

Treatment[1]	Plant height (cm)	No. of panicles/pot	Panicle length (cm)	1000-grain weight (g)	No. of filled spikelets/pot	No. of unfilled spikelets/pot	Harvest index[2]
T_1	102	3a	31	24	2342a	416a	0.49
T_2	105	22ab	22	24	1800ab	221ab	0.55
T_3	99	15bcd	21	24	1428abc	116b	0.43
T_4	101	8d	22	23	590c	127b	0.25
T_5	108	19abc	22	24	1799ab	237ab	0.48
T_6	93	12cd	21	24	710c	270ab	0.32
F-test	NS	***	NS	NS	**	*	NS
CV (%)	5	21	6	4	28	42	32

*, **, ***Significant at the 5, 1, and 0.1% probability levels, respectively.

NS = Not significant; within column means followed by the same letter are not significantly different at the 5% probability level by Tukey's test.

[1]T = timing of 1,200 mg N per 5 kg soil. T1 = all N at sowing; T2 = 1/3 N at sowing + 1/3 N at tillering +1/3 N at panicle initiation; T3 = 1/3 N at sowing + 1/3 N at panicle initiation + 1/3 N at booting; T4 = 1/3 N at planting + 1/3 N at panicle initiation + 1/3 N at flowering; T5 = ½ N at tiller initiation + ½ at panicle initiation; and T6 = 1/3 N at tiller initiation + 1/3 N at booting + 1/3 N at flowering.

[2]Harvest index = grain yield / grain plus straw yield.

of filled grains per panicle on yield were positive, but of secondary importance when compared to the direct effects of panicle density on yield. The number of unfilled spikelets was significantly ($P>0.05$) higher under T_1, the highest grain yield-producing treatment, as compared to T_4 and T_6, the lowest grain producing treatments. This means that when the number of panicles or number of spikelets per unit area increased, spikelet sterility is also increased. This may happen due to higher sink (spikelet number) capacity and comparatively lower source capacity (photosynthesis). This compensatory relationship between panicle density and filled grains is well documented for rice crops (Counce, 1987; Jones and Snyder, 1987). In our study, the filled spikelet percentage was about 85%; under the highest-yielding treatment (T_1). This is an ideal number reported in the literature for this trait under favorable conditions for lowland rice (Yoshida, 1981).

Thousand-grain weight, did not change significantly with N treatments. Variations in grain weight are generally small since seed size is rigidly controlled by the size of the hull (Yoshida, 1981). Under most conditions, the 1,000-grain weight of field crops is a very stable varietal character (Yoshida, 1981). The relative importance of number of panicles, spikelet sterility, and 1,000-grain weight was evaluated by the order of inclusion into a multiple forward step-wise regression procedure and the additional contribution that each yield component made to the total variation in yield. Panicles per pot was the most important component of yield, accounting for 87% of the variation in yield. Spikelet sterility accounted for a 7% variation in yield, and 1,000-grain weight a 3% variation. Grain yield was significantly related to the number of panicles per pot and harvest index, but not to panicle length or 1,000-grain weight (Figure 2). Spikelet sterility was negatively correlated to grain yield.

Although harvest index values did not differ significantly wit N treatments, under the lowest-yielding treatments (T_4 and T_6), the harvest index values were lower as compared to higher yield producing treatments (T_1, T_2, and T_5). The harvest index values reported in the literature for semidwarf indica cultivars is in the range of 0.45 to 0.55 under favorable environmental conditions (Yoshida, 1983).

Nitrogen concentration and N uptake in the dry matter and grains were significantly affected by N treatments (Table 2). The values of N concentration and uptake were significantly higher for T_4 and T_6 treatments as compared to T_1, T_2, and T_5, highest grain yield-producing treatments, respectively. However, N uptake in the grain was significantly lower in the T_4 and T_6 treatments as compared to highest yielding T_1, T_2, and T_5 treatments. This means a major part of the N applied late in the growth cycle of the rice crop (booting and flowering growth stages), was absorbed by the plants, but it remained in the dry matter and was not utilized for improving grain yields.

The N harvest index (NHI) is a measure of N partitioning in rice which provides an indication of how efficiently the plant utilized the acquired N for grain production. The mean N-harvest index values were significantly ($P<0.001$) higher with T_1, T_2, and T_5, the highest grain-producing treatments, as compared to T_4 and T_6, the

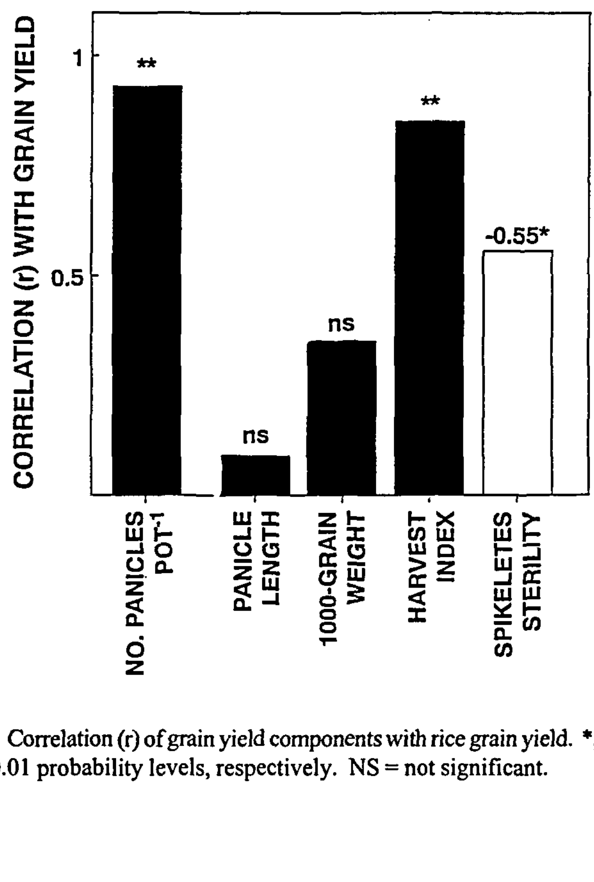

FIGURE 2. Correlation (r) of grain yield components with rice grain yield. *, ** Significant at 0.05 and 0.01 probability levels, respectively. NS = not significant.

lowest grain yield-producing treatments. This difference suggests that the partitioning efficiency of N depends upon when the N is acquired. Physiological processes that have an important influence on N partitioning efficiency were established before the booting and flowering growth stages in the rice crop.

Westcott et al. (1986) measured NHI ranging from 68 to 74% for lowland rice. Dingkuhn et al. (1991) reported NHI ranging from 60 to 72% for three IRRI semidwarf rice cultivars differing in growth duration. These values are similar to those of T_1, T_2, and T_5 treatments of our study.

The lower NHI of treatments T_4 and T_6 suggest that late application of N did not translocate to the grains from the vegetative tissue. There was higher N accumulation in the dry matter under these two treatments as compared to other treatments (Table 2).

Agronomic efficiency (mg grain per mg N applied) and physiological efficiency (mg grain plus straw per mg aboveground plant N) were significantly influenced by N timing (Table 2). Efficiencies with treatments T_4 and T_6 were lower as compared

TABLE 2. Nitrogen concentration, nitrogen uptake, nitrogen harvest index, and nitrogen use efficiency under different nitrogen treatments.

Treatment[1]	N conc. (g/Kg)		Total N uptake (mg Pot^{-1})		NHI[2]	Agronomic[3] efficiency	Physiological[4] efficiency
	DM	Grain	Straw	Grain	%	---------mg/mg-------	
T_1	5c	15b	297c	858a	47a	49a	99a
T_2	8bc	17b	343bc	906a	44a	72ab	76b
T_3	11ab	18b	487abc	627ab	29ab	31ab	74b
T_4	15a	22a	613ab	314bc	12c	16b	60b
T_5	9bc	18b	430bc	773a	36ab	36ab	75b
T_6	14a	23a	750a	173c	15bc	22ab	65b
F-test	***	***	**	***	***	*	***
CV (%)	15	7	23	22	15	32	11

*, **, ***Significant at the 5, 1, and 0.1% probability levels, respectively.

Within column means followed by the same letter are not significantly different at the 5% probability level by Tukey's test.

[1]See Table 1.

[2]Nitrogen harvest index (NHI) = N content in grain / N content in grains and straw.

[3]Agronomic efficiency = grain yield / N applied.

[4]Physiological efficiency = mg of straw and grain yield / mg of N content in straw and grain.

to T_1 and T_2 treatments, which produced the highest grain yields. Both efficiencies were higher with early than with late N applications during the crop growth. Similar results were reported by Castillo et al. (1992) in lowland rice. One important feature of these results is that late application of N during reproductive growth stage did not improve grain yield. This may be due to the number of panicles and the number of grains which were already fixed when the plants received a major part of N at the booting and flowering growth stages.

CONCLUSIONS

Managing the N application to flooded rice is an essential to reduce N losses, improve N use efficiency, and obtain higher yields. We addressed the possibility of synchronizing N supply with rice crop demands to achieve adequate yield-forming components and, consequently, higher grain yield. The N timing treatments significantly influenced dry matter and grain yield. Nitrogen applied in the reproductive growth stage (booting and flowering) did not improve lowland rice grain yield as compared to N applied during early growth stages. Dry matter production exhibited a greater response to late-season application of N than did grain yield. Number of panicles per unit area is the most important yield-contributing trait which can be manipulated significantly with the N fertilization application at an appropriate growth stage during the crop growth cycle. Nitrogen applied late during the reproductive growth stage can be absorbed by the crop, but it is not utilized in grain yield improvement. Although the highest grain yield was obtained with the T_1 treatment (all the N applied at sowing), under field conditions we recommend the T_2 treatment, which produced slightly lower yield (9%) as compared to the T_1 treatment. The reason for this is that denitrification and leaching are the principal sources of N losses from soil plant systems under flooded rice cultivation. In the present study, leaching losses did not occur; but, under field conditions, losses of N by leaching will certainly occur.

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